Innovations in Micro-Analytical Systems for Oil and Gas Applications

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Albuquerque, New Mexico

ASME-Petroleum

Emerging Technologies Forum

Houston, Texas

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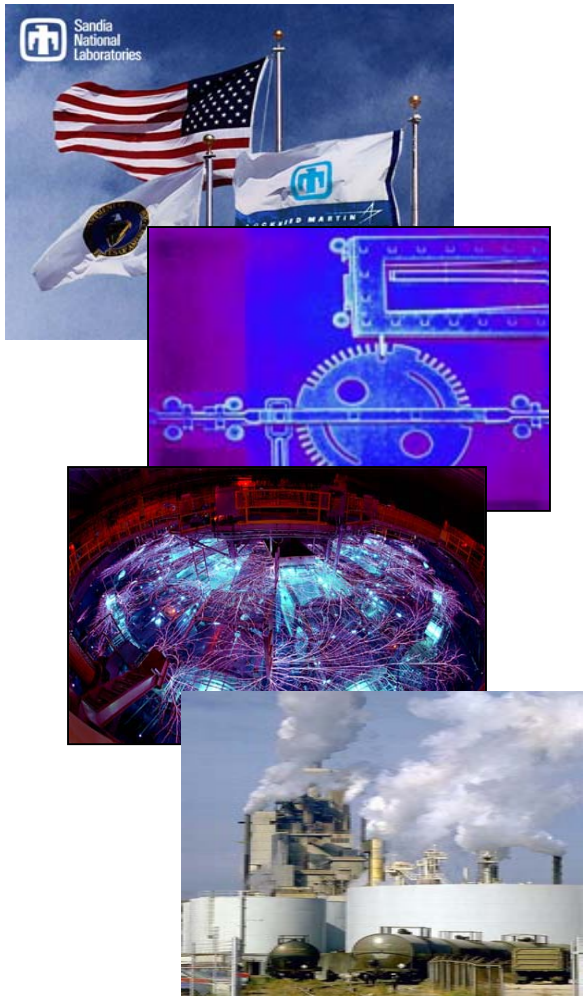
Presentation Overview

- Overview of Sandia National Laboratories
- The MEMS Revolution
- Some Example micro-Analytical Technologies
- Potential Oil and Gas Applications
- Summary



Sandia's missions are grouped into four Strategic Business Units

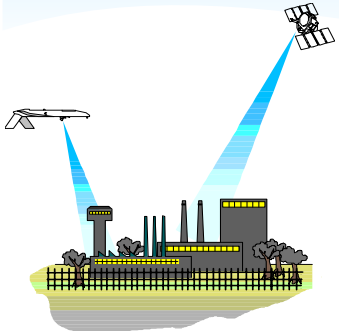
Nuclear Weapons

Sustain Nuclear Weapons Stockpile

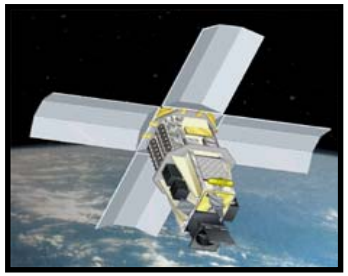
Safe, Secure, Reliable Weapons

Nuclear Non-Proliferation

Reduce Vulnerability to Weapons of Mass Destruction



Detection



Surveillance

Energy and Critical Infrastructures

Advance Surety of Global Infrastructures

Energy

Transportation

Environment

Information

Emerging Threats

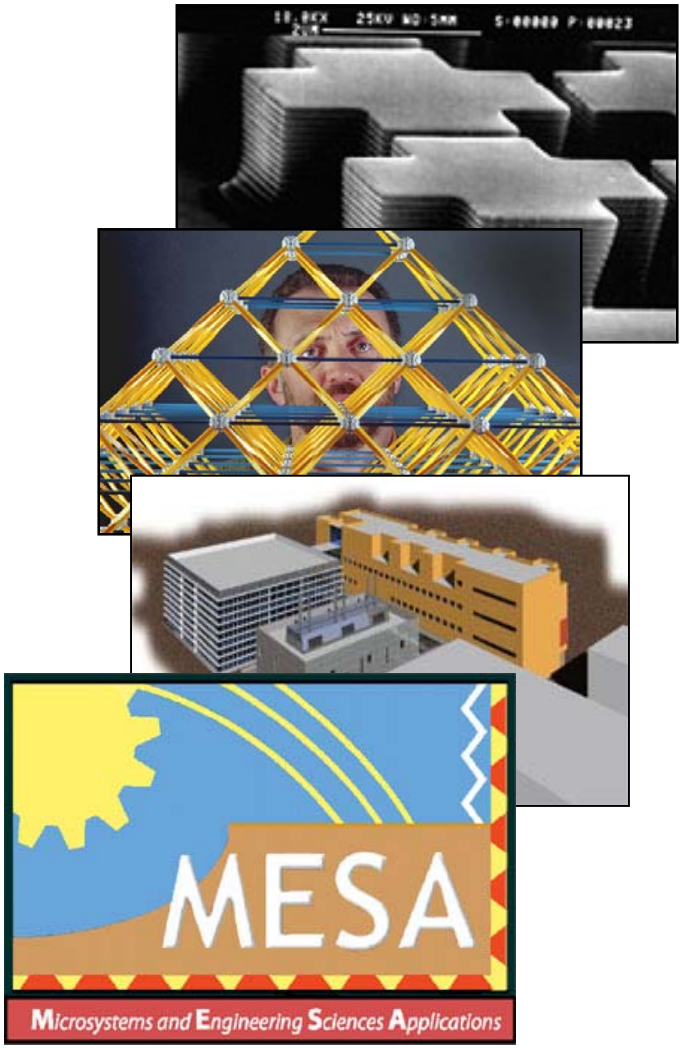
Enhance National Security Measures

Architectural Surety

Anti-crime and anti-terrorism technology

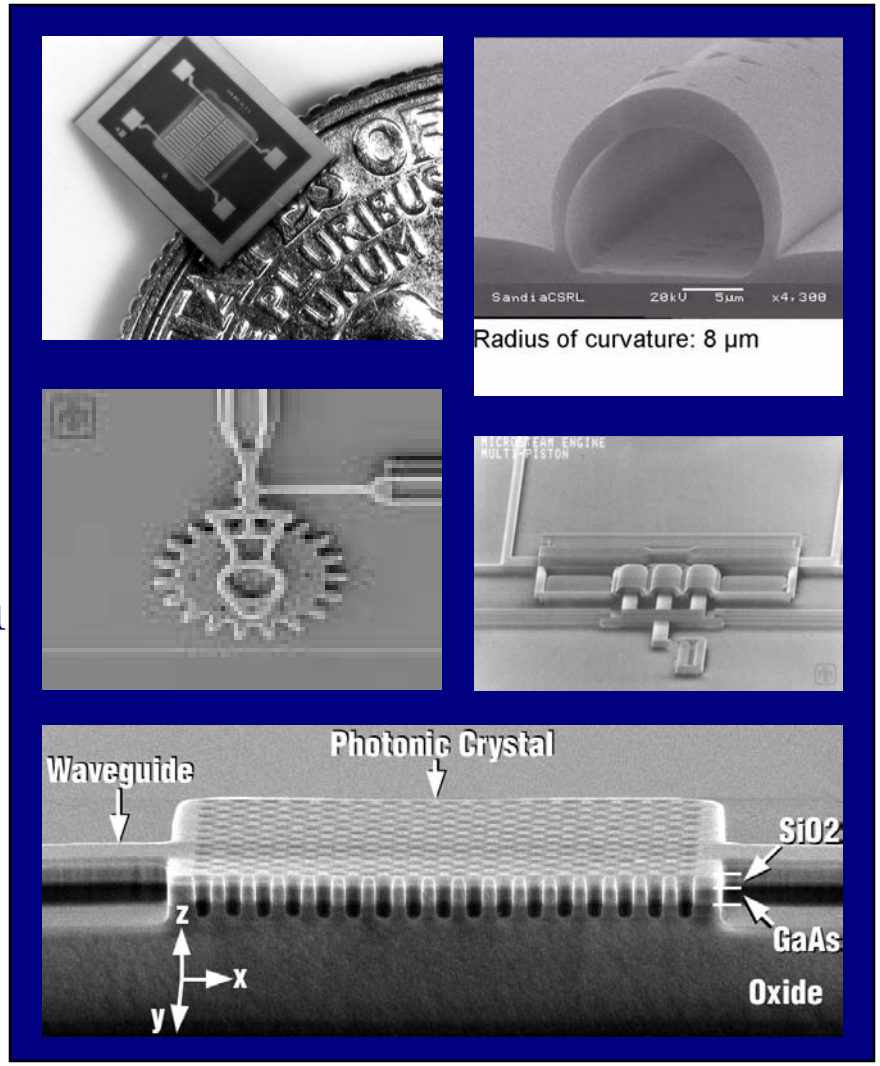
Micro- and Nano-technology for Sensor Development

- Micro-technology -- at the “chip” level
- Nano-technology -- at the “molecular” level
- Low-cost, large scale production
- Specifically tailored “disposable” sensors
- High-density, networked sensor systems
- Sandia MESA facility-- part of the DOE National Nanotechnology Initiative



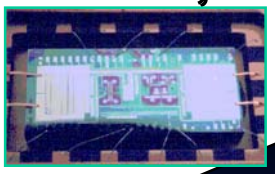
The Next-generation Microchip

- Electronic circuitry
- Mechanical work
- Gas/fluid handling
- On-chip lasers
- On-chip tunable diffraction gratings
- Optical/RF channeling

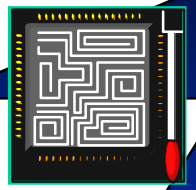


Sandia's Enabling Capabilities Produce Miniature Sensors, Processors, and Communication Systems

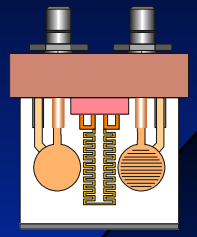
Sense, Process, Communicate

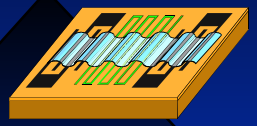


Micromachines, Microelectronics

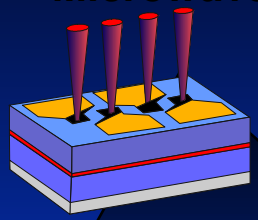


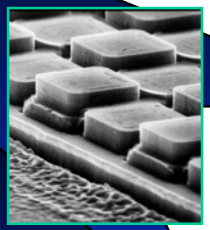
Microsensors





Photonics, Microwave Circuits

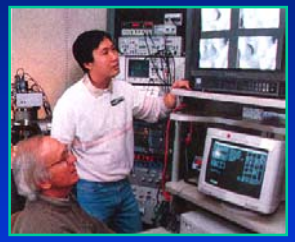




Microelectronics Development Laboratory
MDL

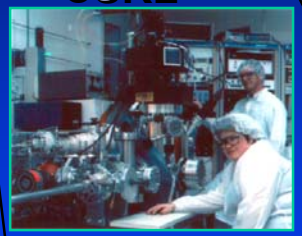
Over 30,000 ft² of clean room, 0.6 μm CMOS Fabrication Facility

Integrated Materials Research Laboratory
IMRL



Materials Fabrication and Characterization, including Plasma Deposition and Surface and Interface State Characterization

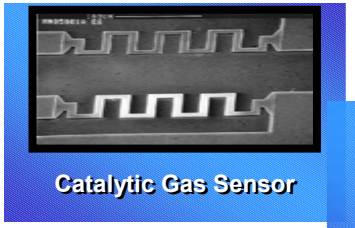
Compound Semiconductor Research Laboratory
CSRL

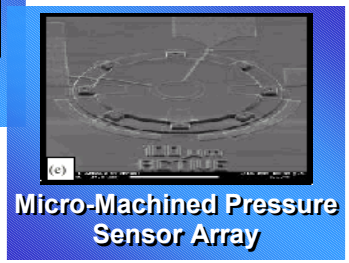


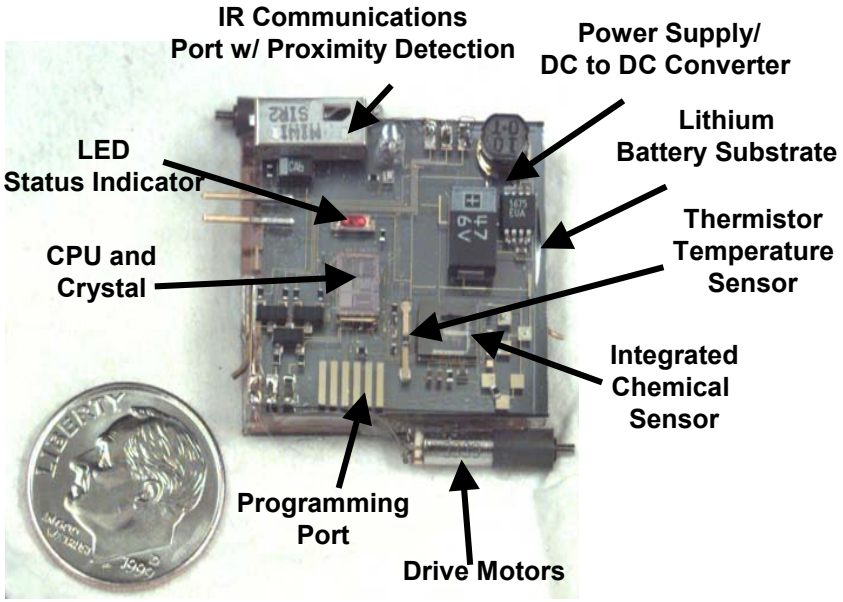
MOCVD, MBE Deposition, Electron Beam Lithography, Reactive Ion Beam Etching

Microelectronics Based Sensor Research and Development

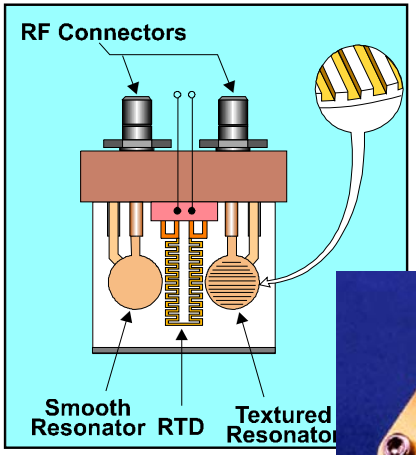
- Developing a variety of micro-sensors to measure physical and chemical properties
  - Surface acoustic wave sensors for organics
  - FET Hydrogen sensors
  - Fiber optic based sensors
- Micro-sensors enable applications in harsh environments
- Advanced, low-cost sensors coupled with innovative monitoring concepts can enable active control of systems

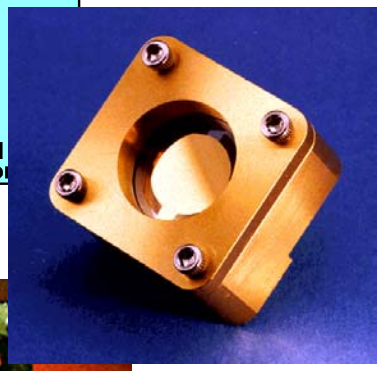


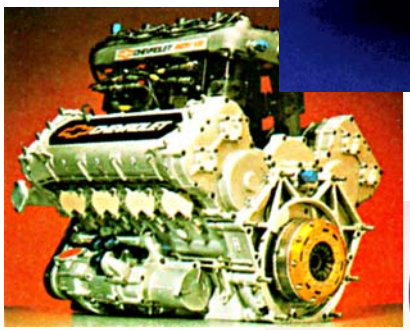




Bulk Resonator Fluid Monitor







Features:

- Piezoelectric quartz electrically excited into shear-mode resonance
- Fluid contacting resonator changes resonant frequency and damping
- Immersible sensor provides real-time, *in situ* measurement of density and viscosity

Applications:

- Engine oil monitoring (USCAR)
- Mixed-waste fluid monitoring (DOE/EM-50)
- Hand-held viscometer (DJ Scientific)

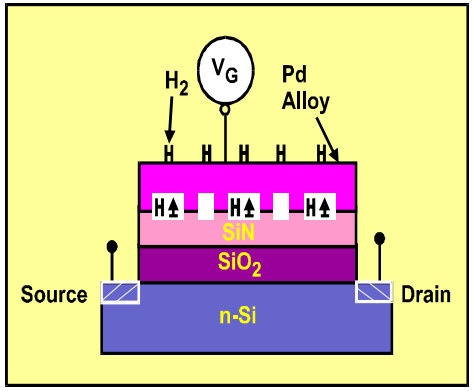
Integrated Hydrogen Sensor

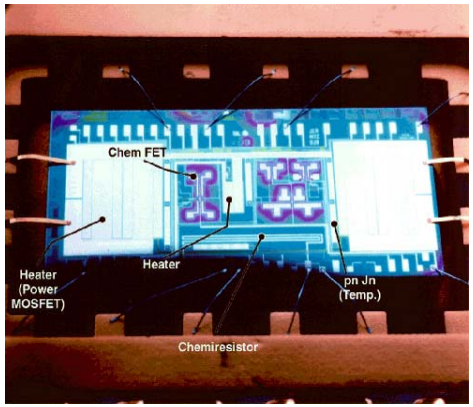
Features:

- FET formed on Si with Pd/Ni gate
- Threshold voltage changes when H_2 absorbed by gate
- Integrated sensor combines FET, chemiresistor, heaters, and control electronics

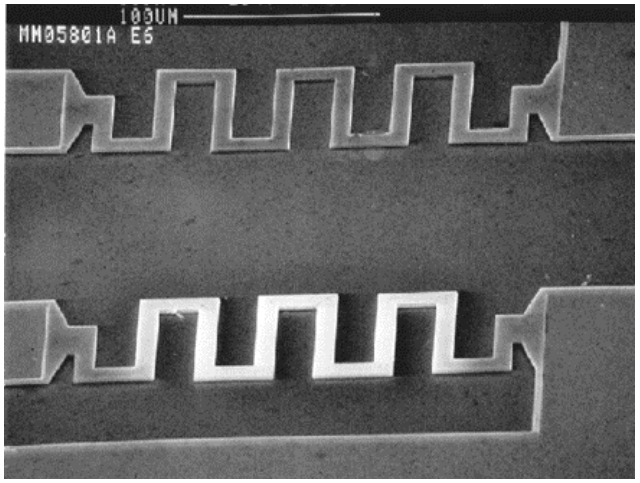
Applications:

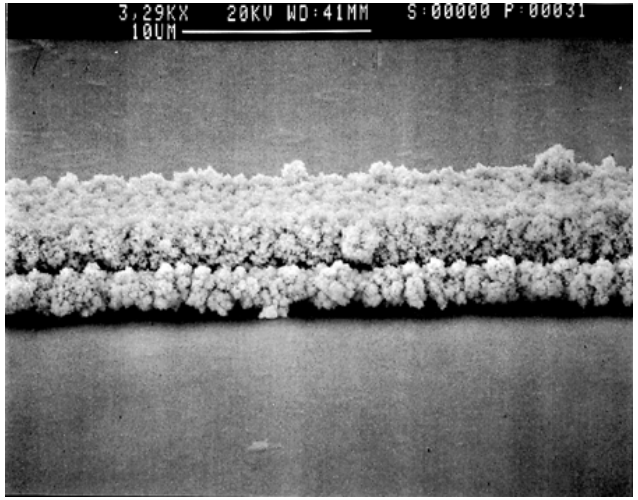
- Hydrogen fuel leaks (NASA)
- Corrosion monitoring (DP)
- Monitoring nuclear material in storage (Los Alamos)





Micro-machined Catalytic Gas Sensor





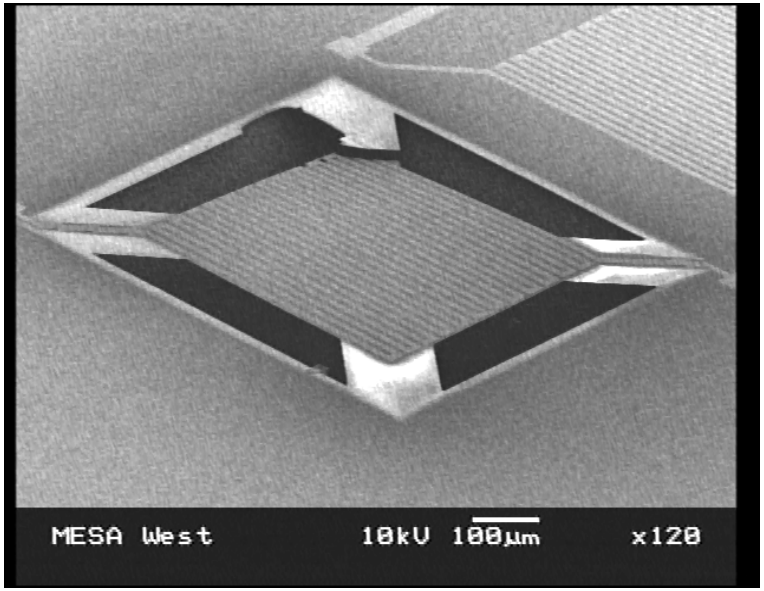
Features:

- **Suspended poly-Si filament with catalytic Pt coating is heated by current flow**
- **Combustible gases react with O_2 on filament, releasing heat**
- **Gas concentration determined from power required to maintain temperature**

Applications:

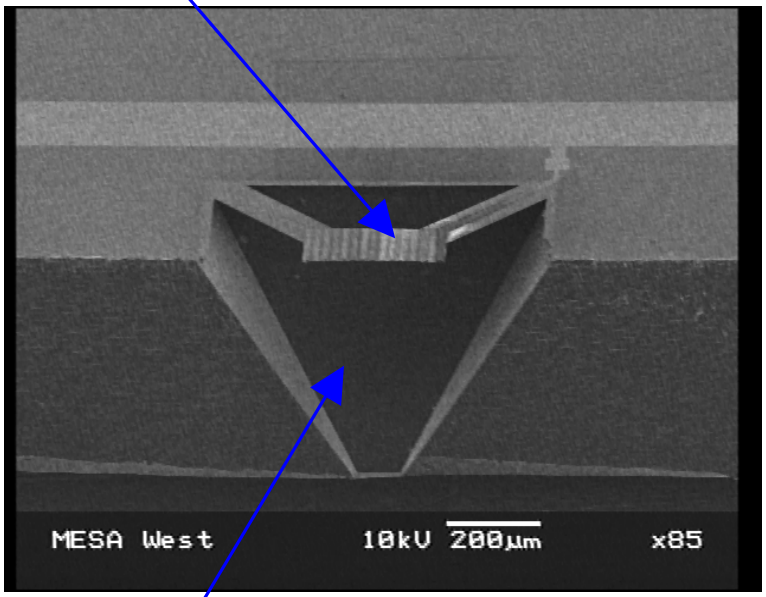
- **Natural gas BTU monitor**
- **Catalytic converter monitor**

Micro Thermal Conductivity Detector



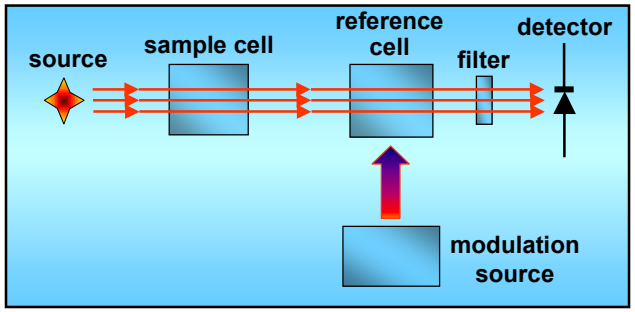
L = 500 µm C = 100 µm

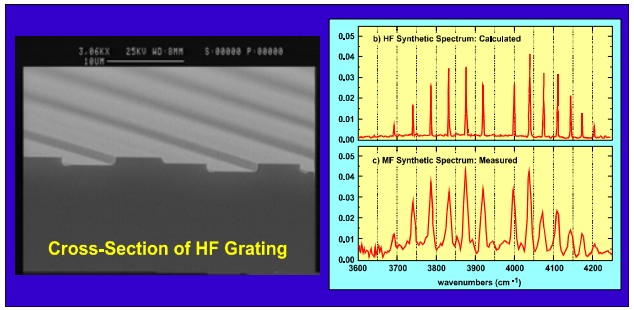
Suspended membrane

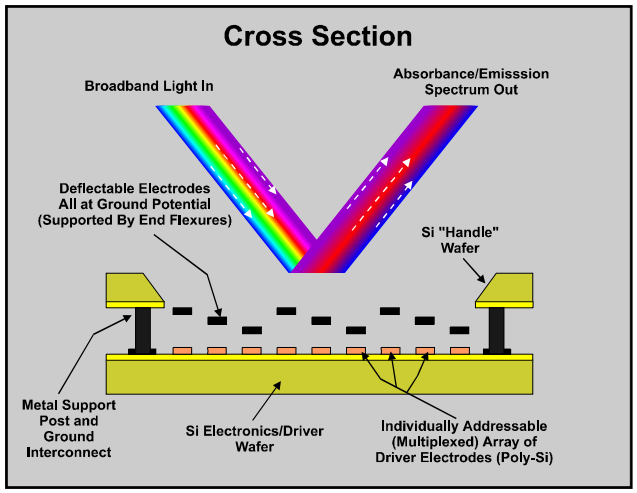


Gas channel

Micromachined Diffraction Grating







Features:

- Optical correlation spectrometer identifies spectral components
- Reference spectrum generated by an aperiodic diffraction grating
- Generate arbitrary reference spectra using electrically adjustable diffractors

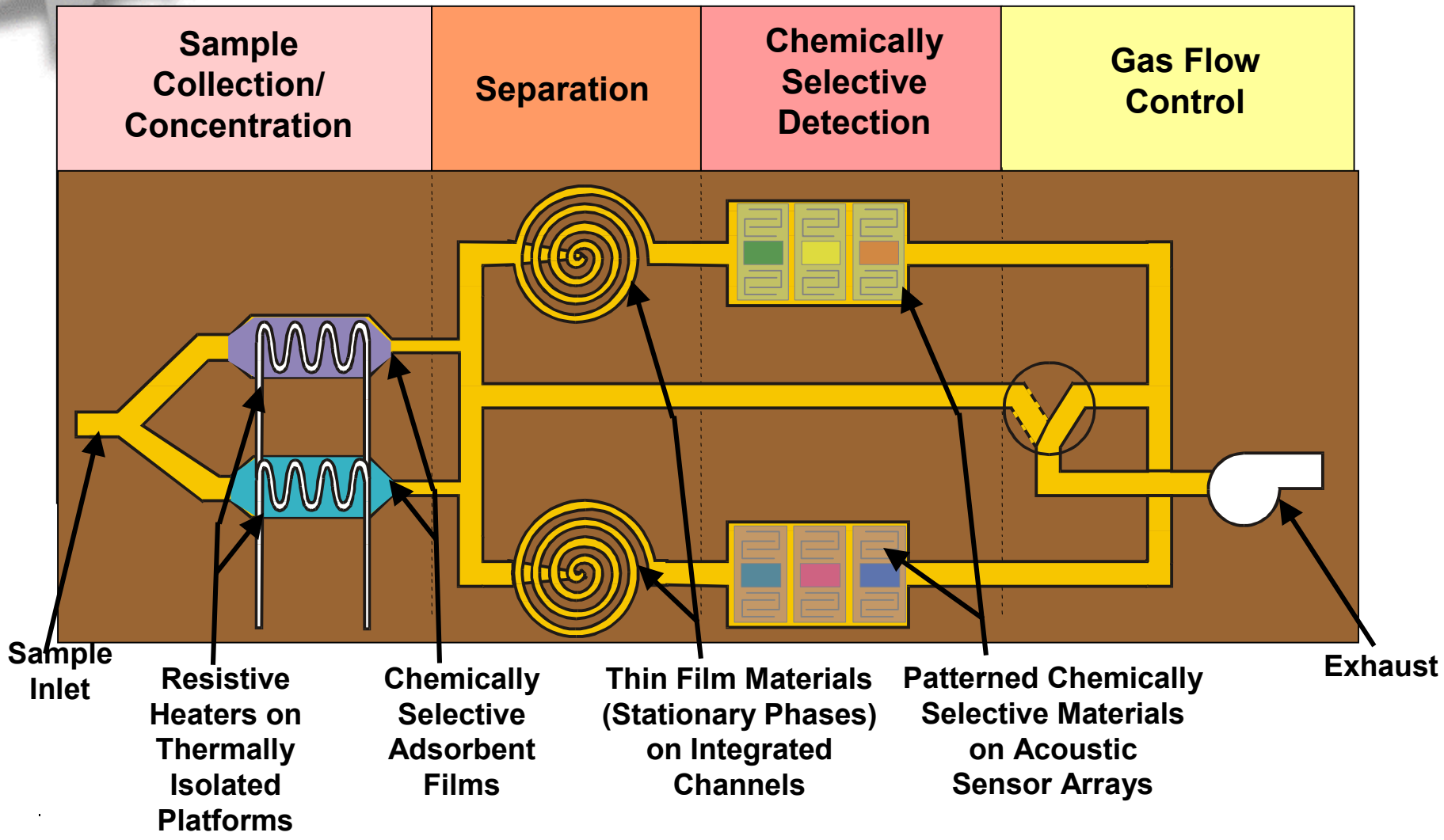
Applications:

Chemical agent plume analysis

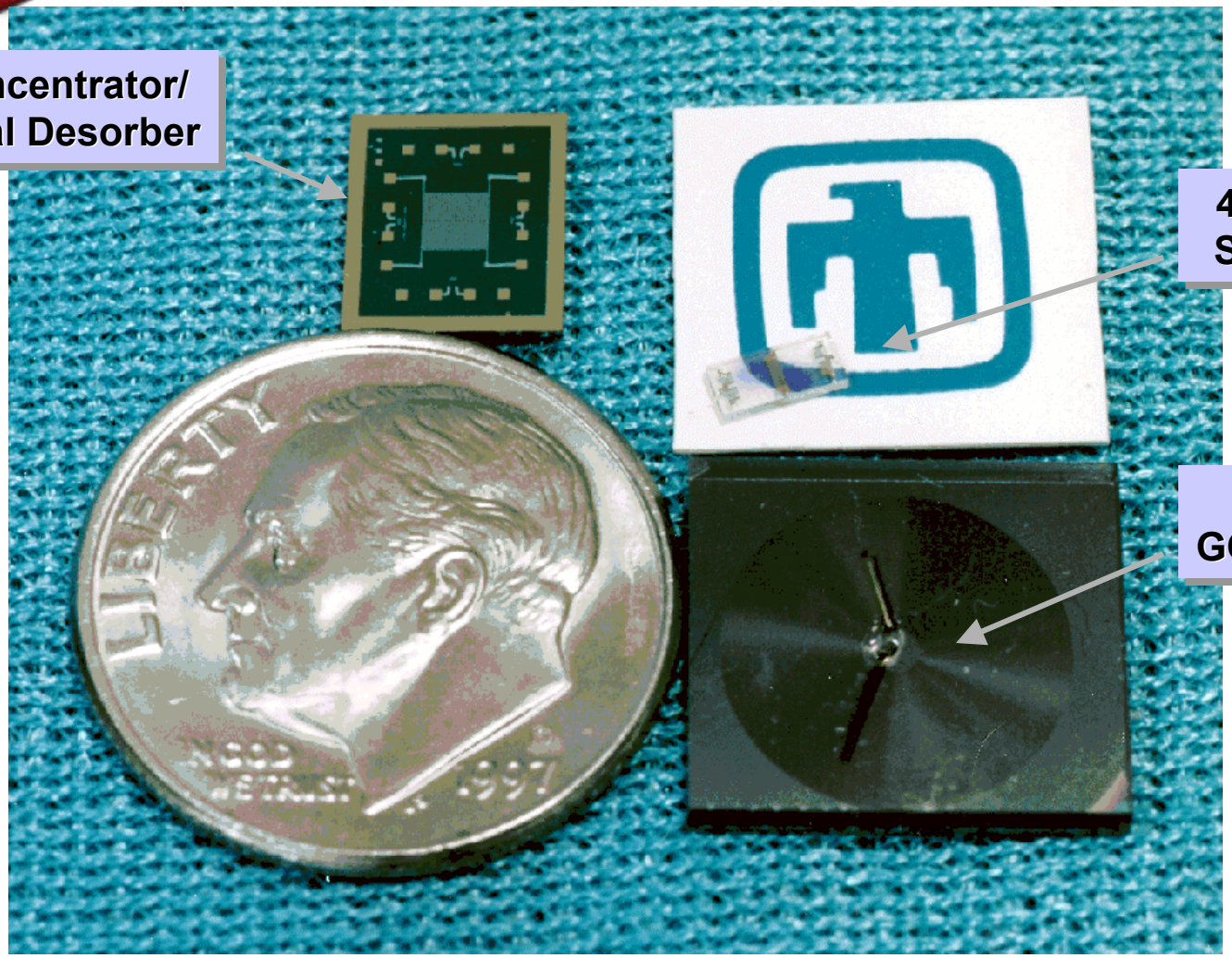
Refinery fugitive monitoring

Stack monitoring, plant effluent monitoring

microChemLab Gas Phase Analysis System



GC Micro-components

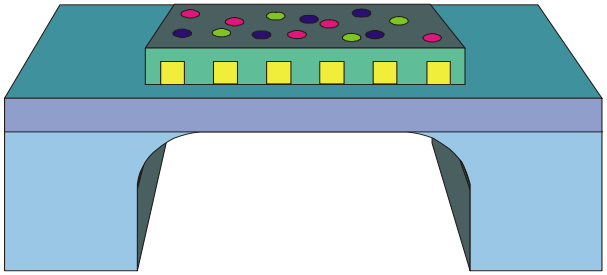


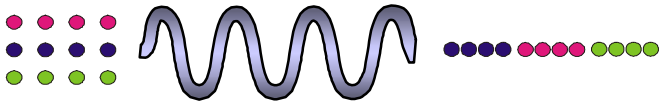
Preconcentrator/
Thermal Desorber

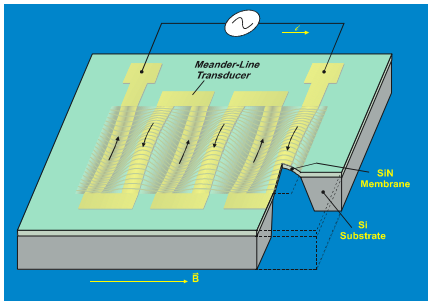
4-Channel
SAW Array

1-Meter
GC Column

MicroChemLab - Chemical Analysis on a Chip



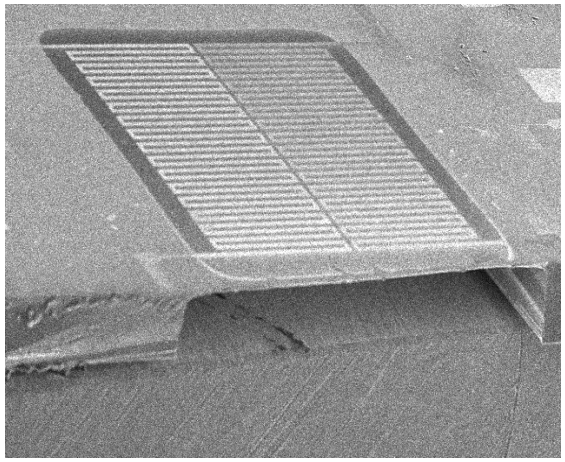


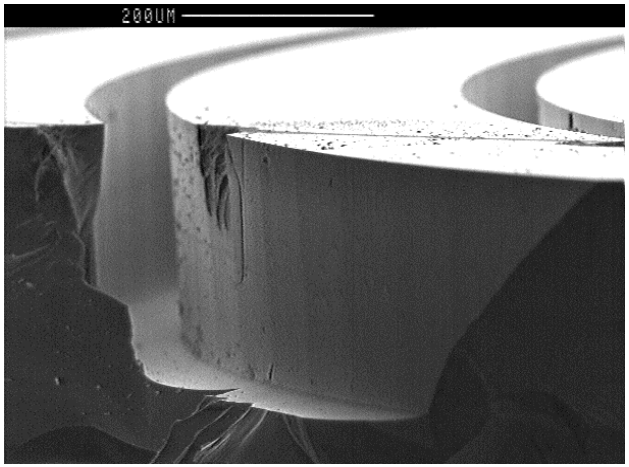


Preconcentrator accumulates species of interest

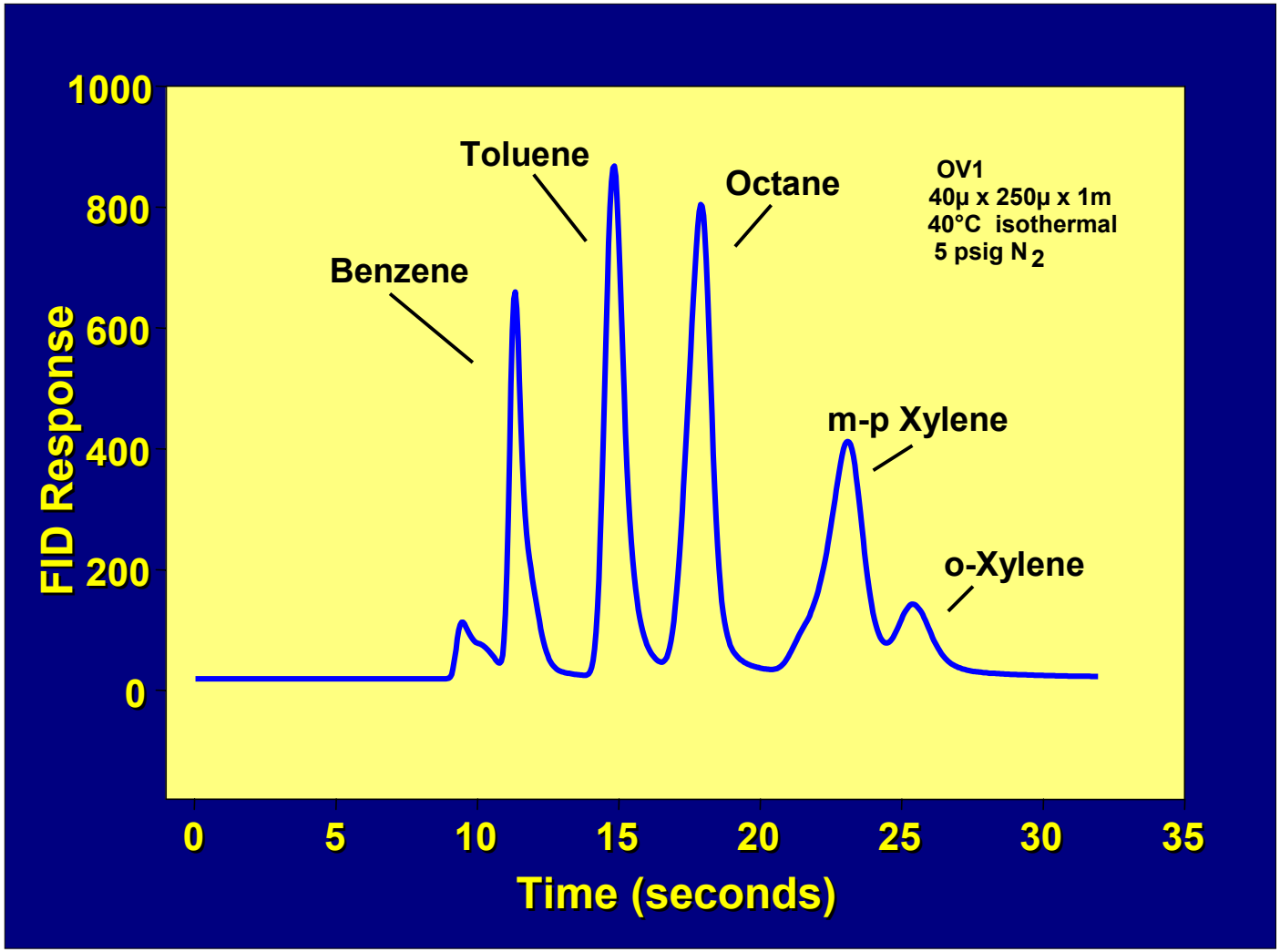
Gas Chromatograph separates species in time

Acoustic Sensors provide sensitive detection



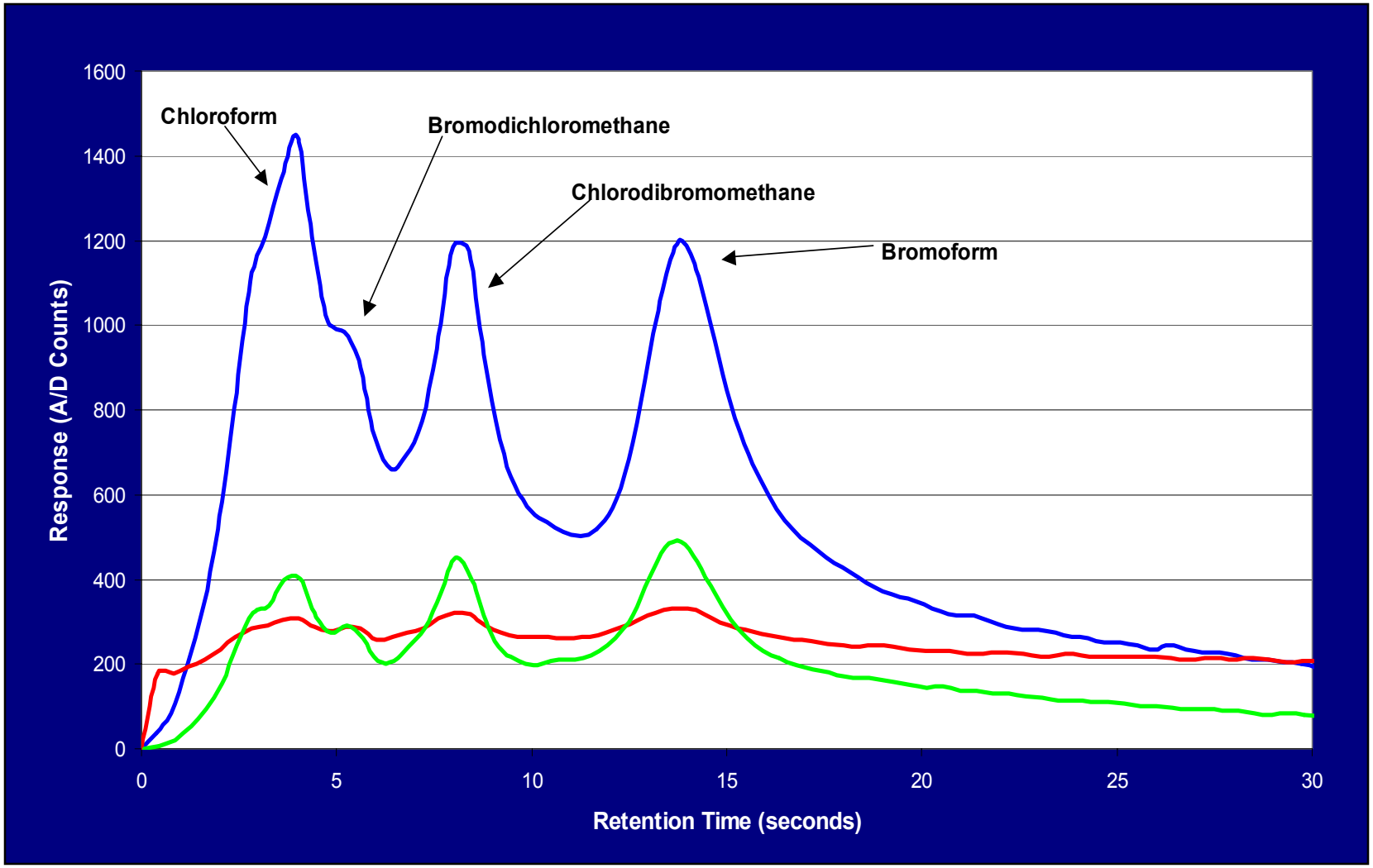


High Speed Separation of Common Hydrocarbons Using µChem Lab GC Column

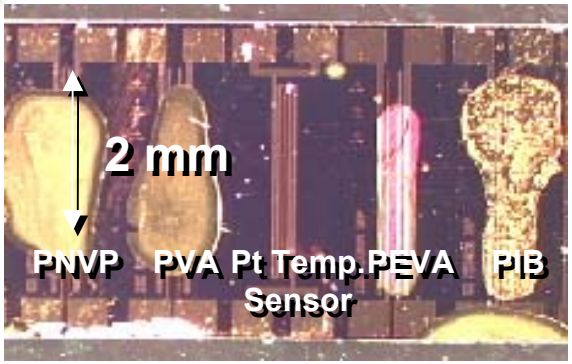


microChemLab Gas Analysis

Trihalomethane-in-water Mixture, 150 ppb
60 sec Collection, 30 sec Analysis



Chemiresistor Sensors
in situ Monitoring of Volatile Organic Compounds



Chemiresistor Array
(4 Different Polymer Films)

Waterproof sensor package for monitoring well or cone penetrometer

Continuous *in situ* monitoring of volatile organic compounds (toxic chemicals, explosives, etc.)

- Polymer film with conductive particles forms chemically sensitive resistor
- Small, low-power system with no pumps or valves
- Sensor array can provide analytic discrimination

Field testing for vadose zone application is presently underway

Sandia National Laboratories

Smart Fish

Micro-Sensors Systems for *in-situ* Pipeline Measurements

Problem:

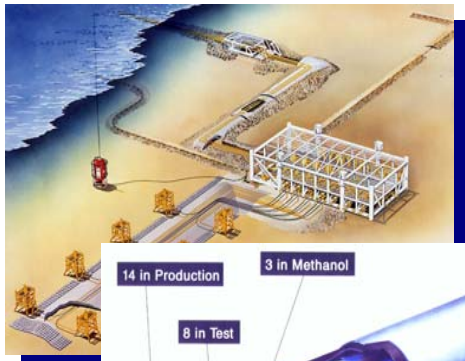
• What is the temperature profile and corrosion potential in sub-sea pipeline oil? (e.g. North Sea Field)

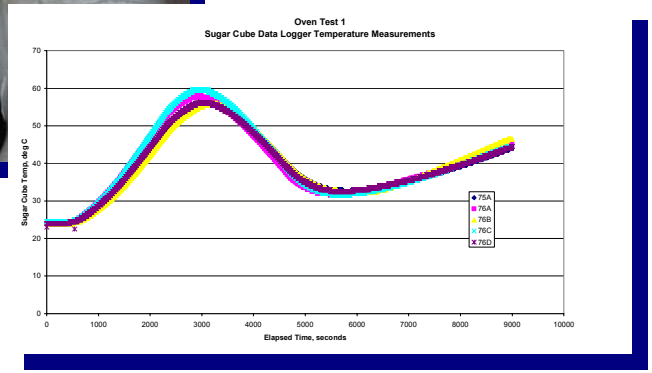
Conceptual Solution:

• Use low-cost *in-situ* sensors to measure bulk oil properties during pipeline startup

• Design or optimize sensors to measure key parameters in gas, water and oil phases

• Use the data to characterize oil, optimize heat inputs, flow additives

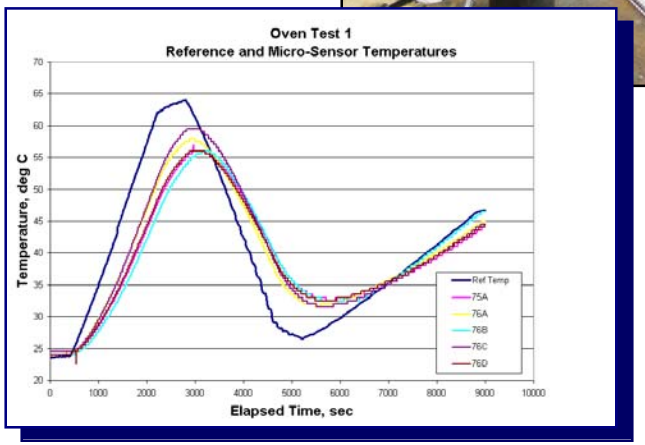




In-situ Temperature Sensor

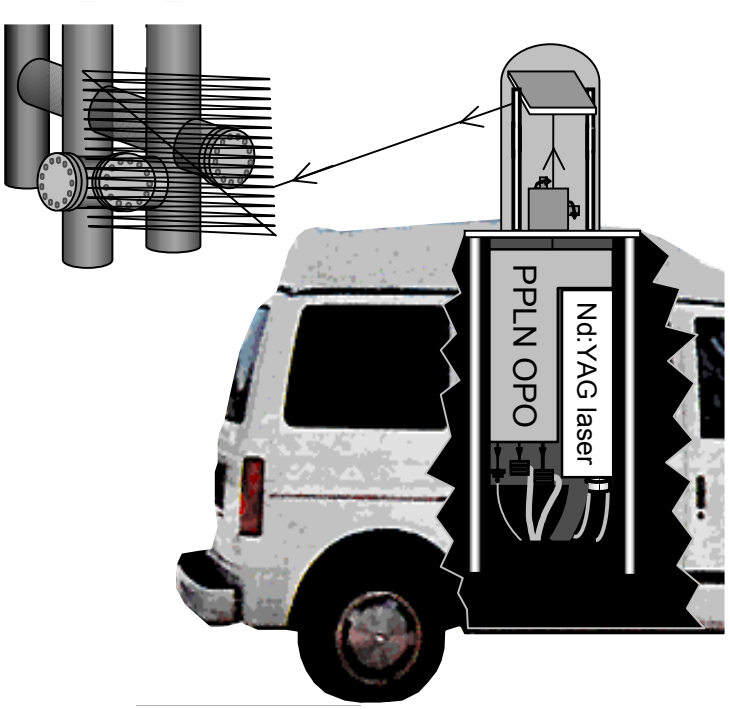
Early Results Look Promising

- Preliminary testing of low-cost commercial product underway
- ~20-mm cube with battery, thermocouple, 2000+ data point storage and wireless interface for data download. Data rates up to 1/sec.
- Initial tests in air show functionality up to 115 deg C and pressures up to 2000 psi.
- Improved encapsulation, added gas sensors (e.g. hydrogen) could result in a low-cost useful sensor
- Design of sensor launch and retrieval system needs to be considered

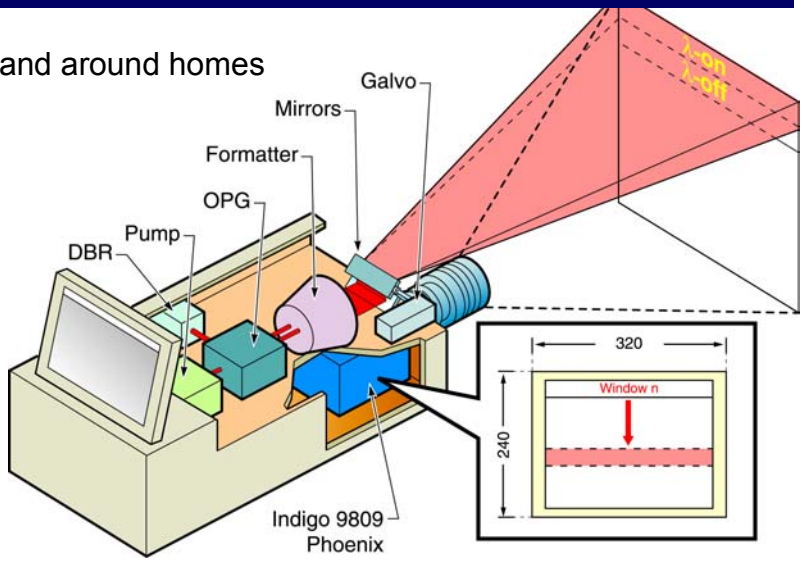


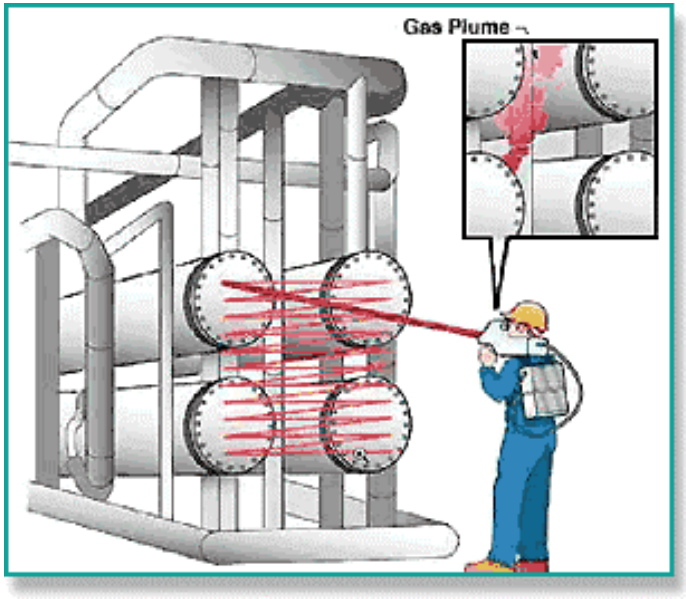
Remote Sensing Leak DetectionTechnology

Vehicle-mounted imager
(refineries, gas distribution)



In and around homes

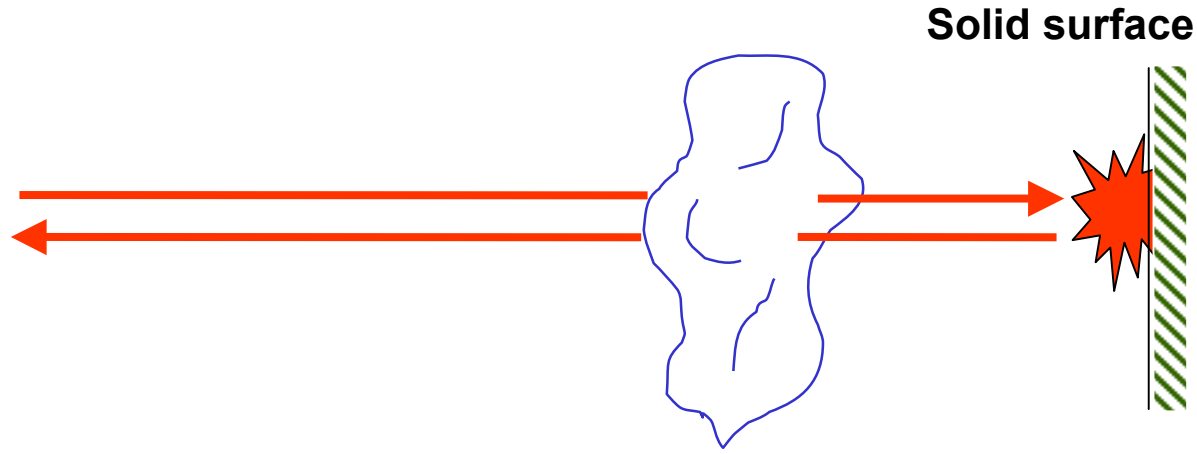


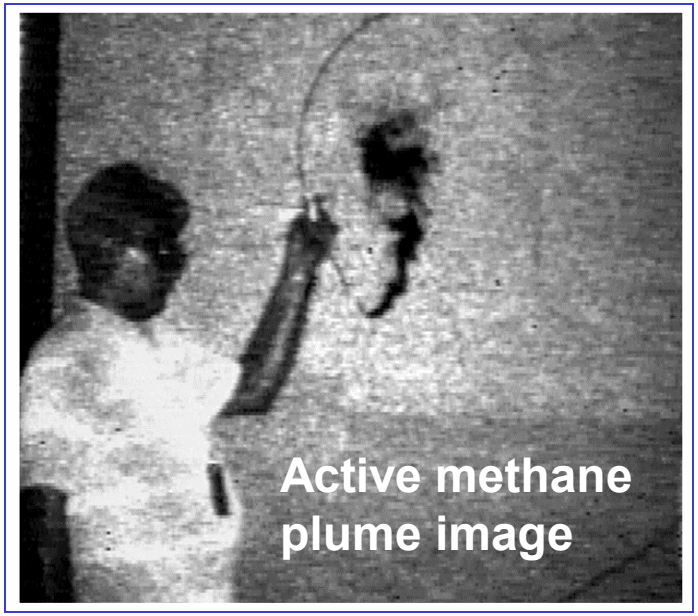


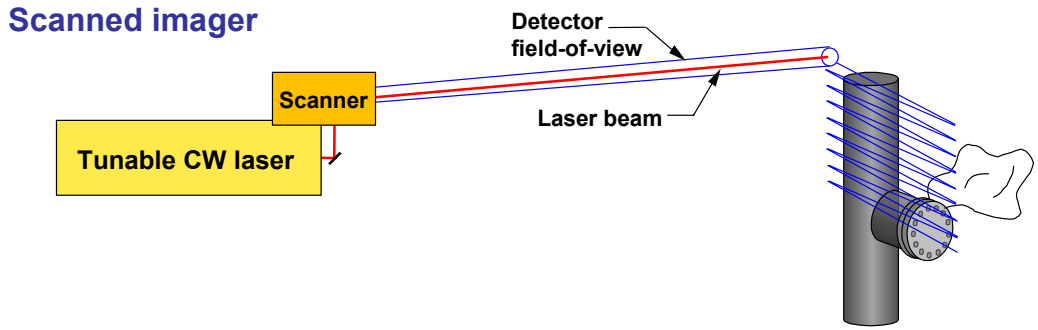
Refineries,
compressor
stations

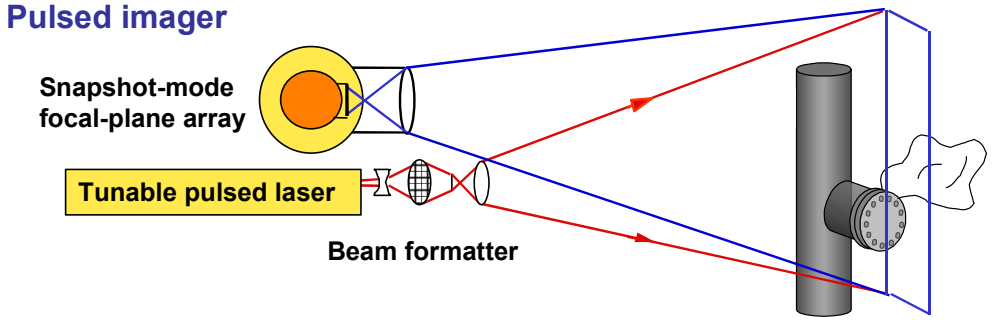
Technology is adaptable to other remote applications.

Remote Imaging or Mapping Simplifies Plume Detection





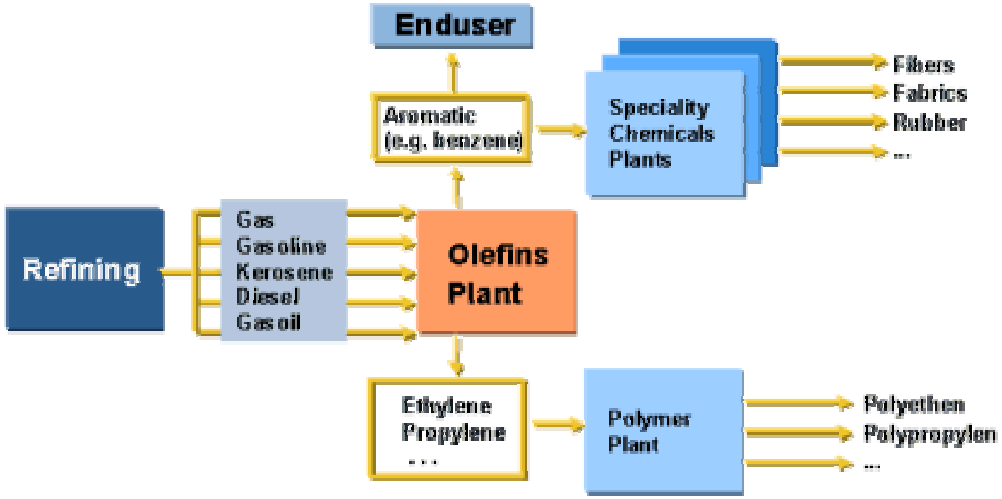




GC micro Controller for Process Control

Problem Statement

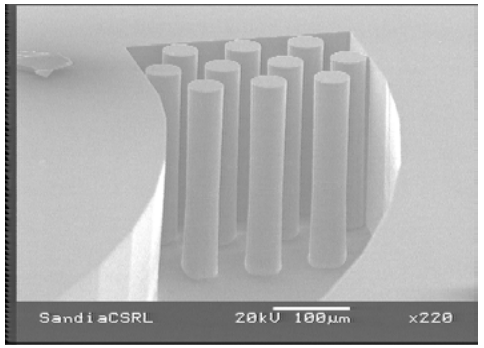
- Ethylene: high-volume domestic and worldwide production
- 1999 US production ~26 M ton
- Production via dehydrogenation of ethane feedstock
- Acetylene is produced by excess dehydrogenation
- Acetylene content controlled by catalyzed reaction in ARU requiring process feedback control
- Disrupt conditions in ARU occur on short (< 3min) time scales
- Avoid reactor runaway, flaring, out-of-spec. product
- Reduce overall energy consumption

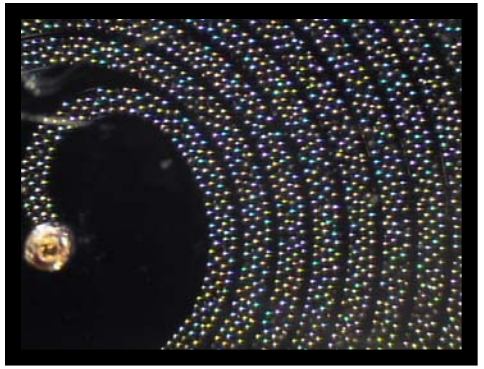


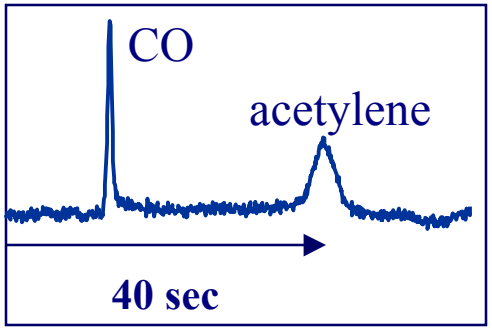
A micro GC Controller Solution

System Features:

- Employ low-cost MEMS micro-GC technology
  - Packed micro-column
  - micro-fabricated sampling valve
  - Pulsed discharge ionization detector
- Fast, real-time process control for enhanced process energy efficiency
- Faster (<1 min cycle time) process monitoring
- Multiple-point process monitoring for ARU stages
- Small-footprint process monitoring





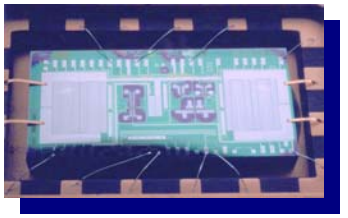


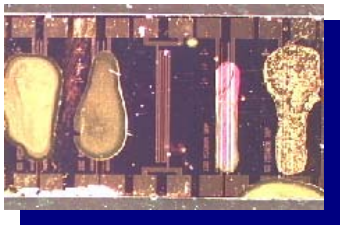
Potential Oil and Gas Applications for micro-Analytical Systems

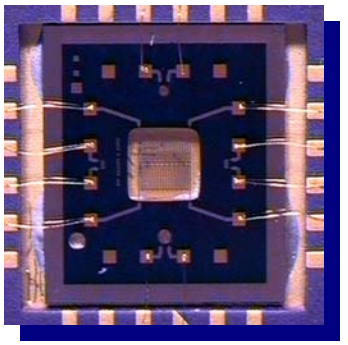
- Low-cost in-situ flow and product assurance
- Continuous in-pipe corrosion monitoring
- Low-cost, real-time, networked natural gas heating value sensor
- Down-hole drilling organic vapor sensor
- Low-cost, high-density, refinery process control
- Improved systems for refinery fugitive leak detection
- Networked sub-sea pipeline leak detection systems
- Sensors for live-in-the-pipe robotic surveillance systems
- Others….?

Summary

- Many nano- and micro-technology sensor applications await discovery
- *In-situ,* low-cost, expendable micro-sensors may offer attractive options for better flow assurance or process control in the oil and gas industries
- R&D leveraging opportunities exist with many DoD/military programs
- Continuing dialogue with the oil and gas industry is essential in order to steer development efforts toward this industry sector
- Product refinement and development requires strong partnerships with the commercial sector







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